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# ***PowerFibers - Thin-Film Batteries on Fiber Substrate***

**Bernd J. Neudecker and Martin H. Benson**

***ITN Energy Systems,  
8130 Shaffer Parkway, Littleton, CO 80127, USA***

**DARPA Synthetic Multifunctional Materials (SMFM) Program  
Dr. Leo Christodoulou, DARPA, SMFM Program Manager  
Dr. Steven Fishman, ONR, COTR**



ITN

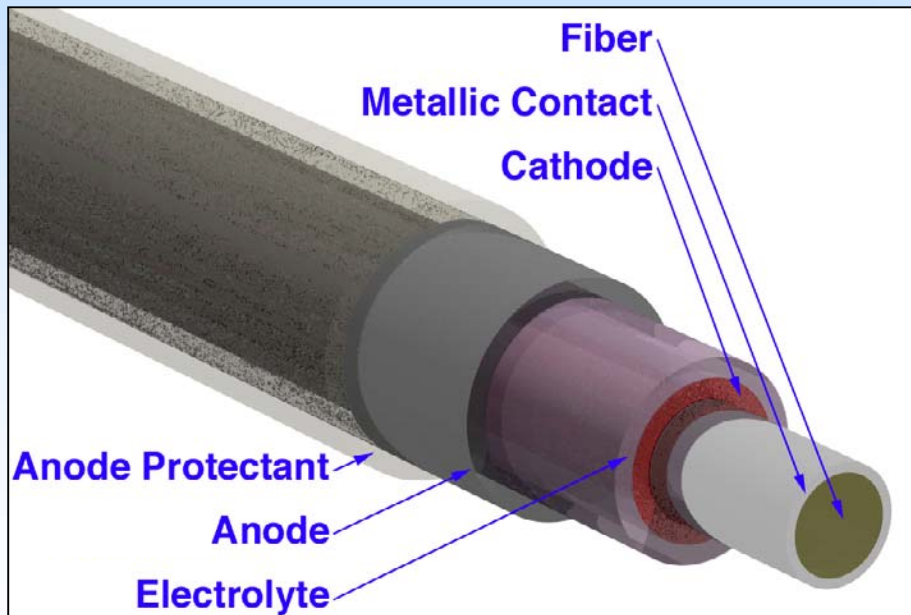
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# The Concept: PowerFiber $\Rightarrow$ PowerComposite

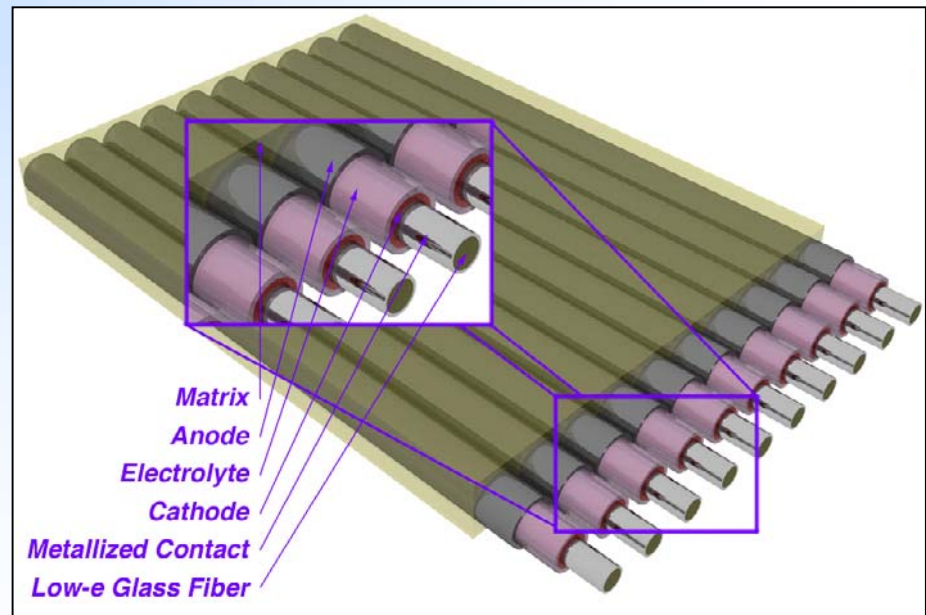
## ■ Objectives:

- 1) Fabricate solid-state thin-film batteries directly onto structural fibers
- 2) Incorporate these “PowerFibers” into structural composites and fabrics

### “PowerFiber”



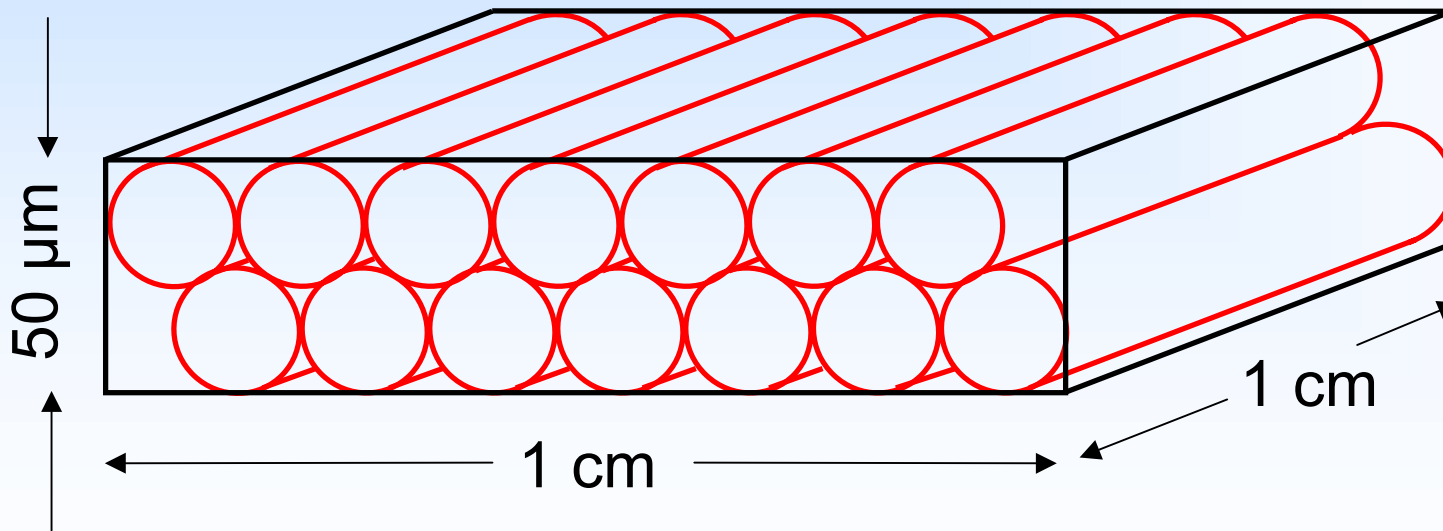
### “PowerComposite”



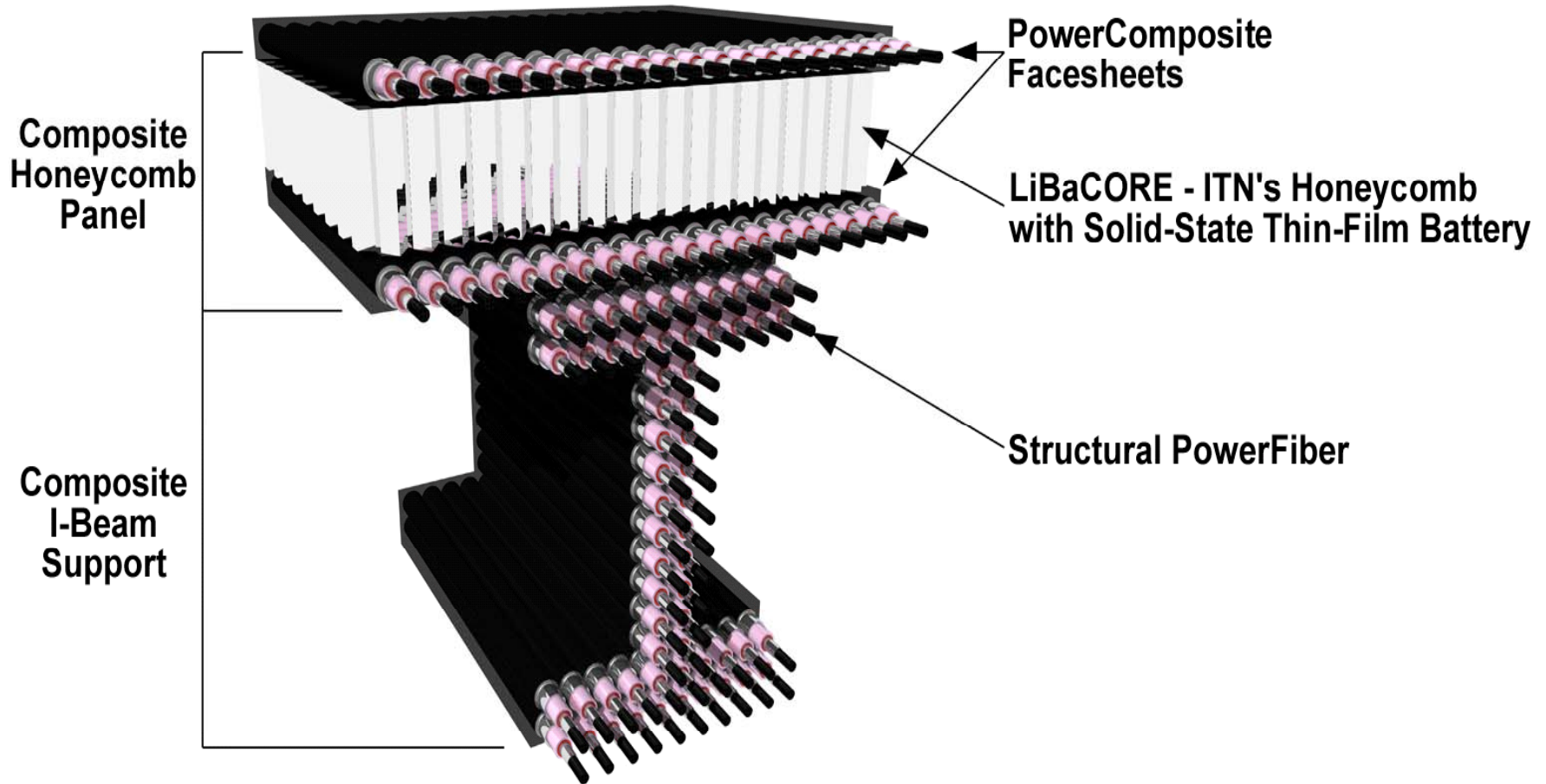
# Energy, Power (Thin-Film Batteries) = Proportional to Battery Area !

## ■ Substrate Area: Foil vs. *Fiber Stack*

Double-sided foil substrate (50 $\mu\text{m}$ thick)	=	2 $\text{cm}^2$
1 Layer of fibers (50 $\mu\text{m}$ in dia.)	=	3.14 $\text{cm}^2$ ( 57% more area)
2 Layers of fibers (25 $\mu\text{m}$ in dia.)	=	6.28 $\text{cm}^2$ (214% more area)
3 Layers of fibers (17 $\mu\text{m}$ in dia.)	=	9.42 $\text{cm}^2$ (371% more area)

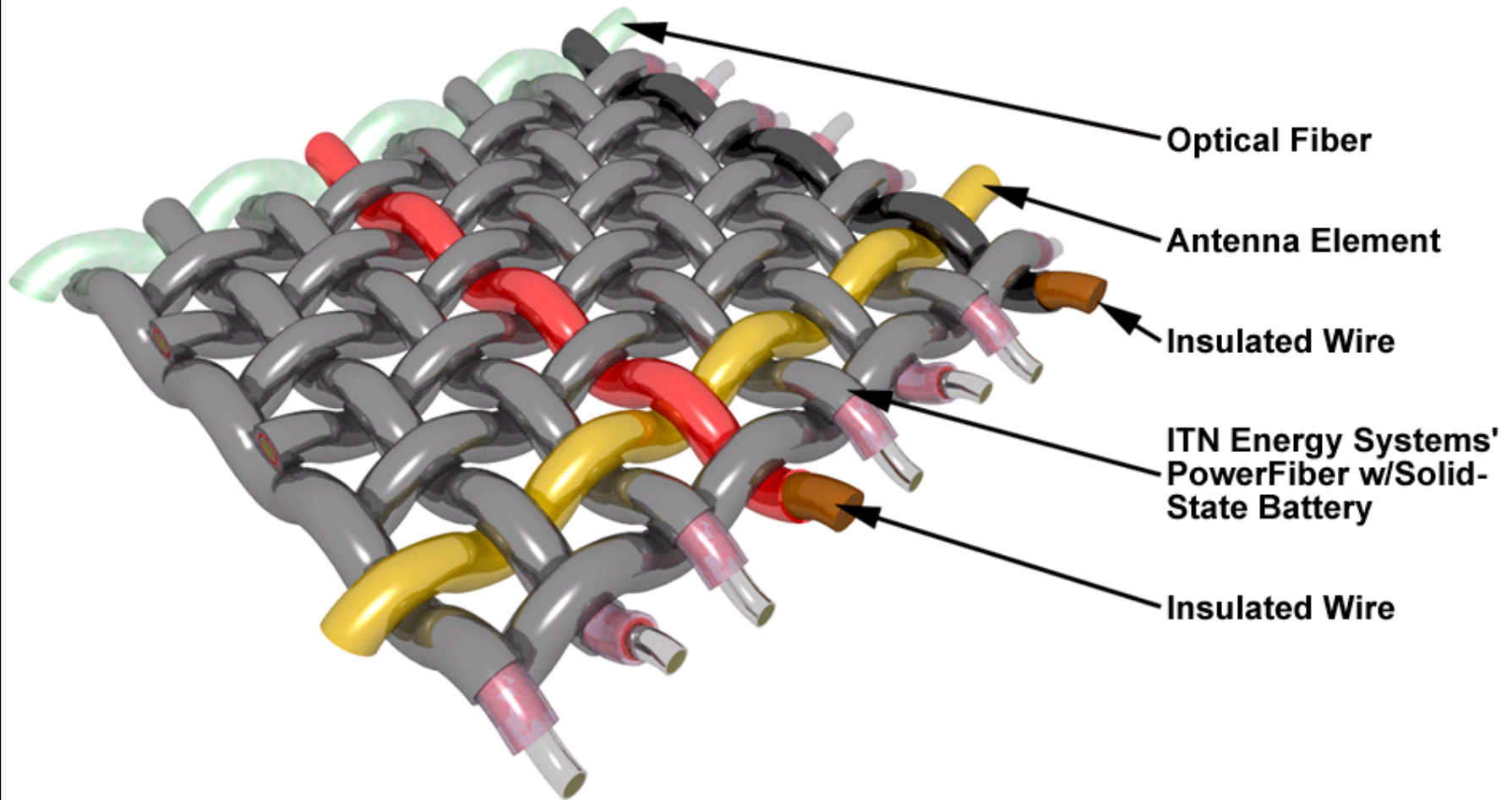


# PowerComposite Applications





# ITN's ElectroTextiles Concept: PowerFiber $\Rightarrow$ PowerWeave

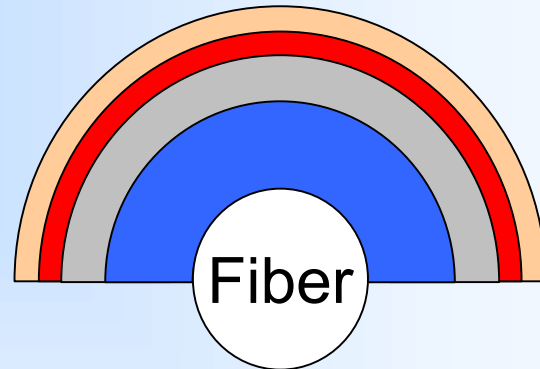
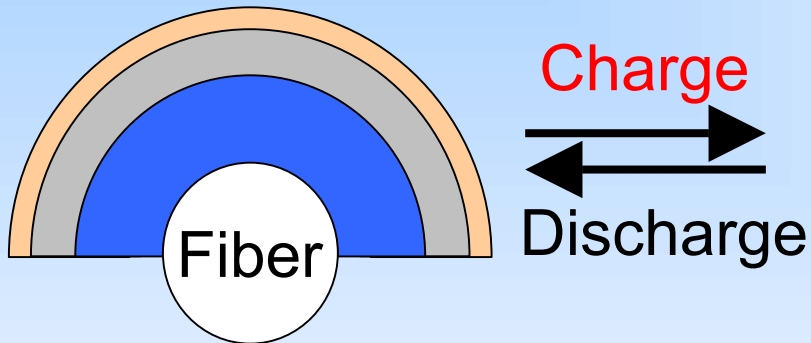


# "Li-Free" Battery Configurations

## Cathode (+) = Only Initial Li Source

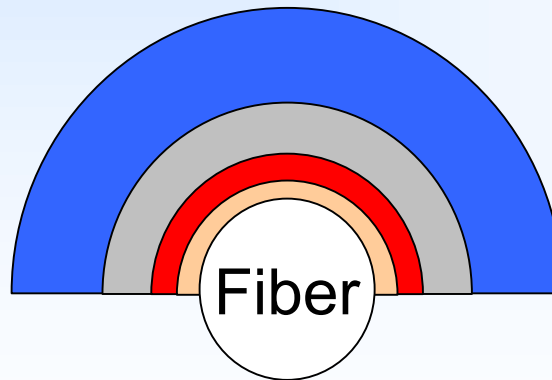
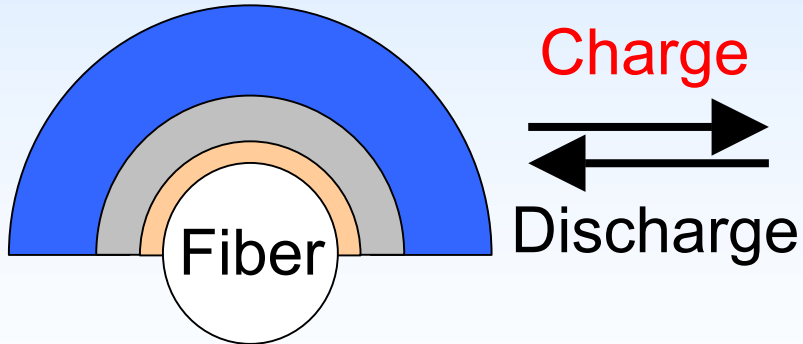
As-Fabricated

During Operation



**"Li-Free"**

**Cathode (+)**  
**Electrolyte**  
**Plated Li**  
**Cu acc (-)**

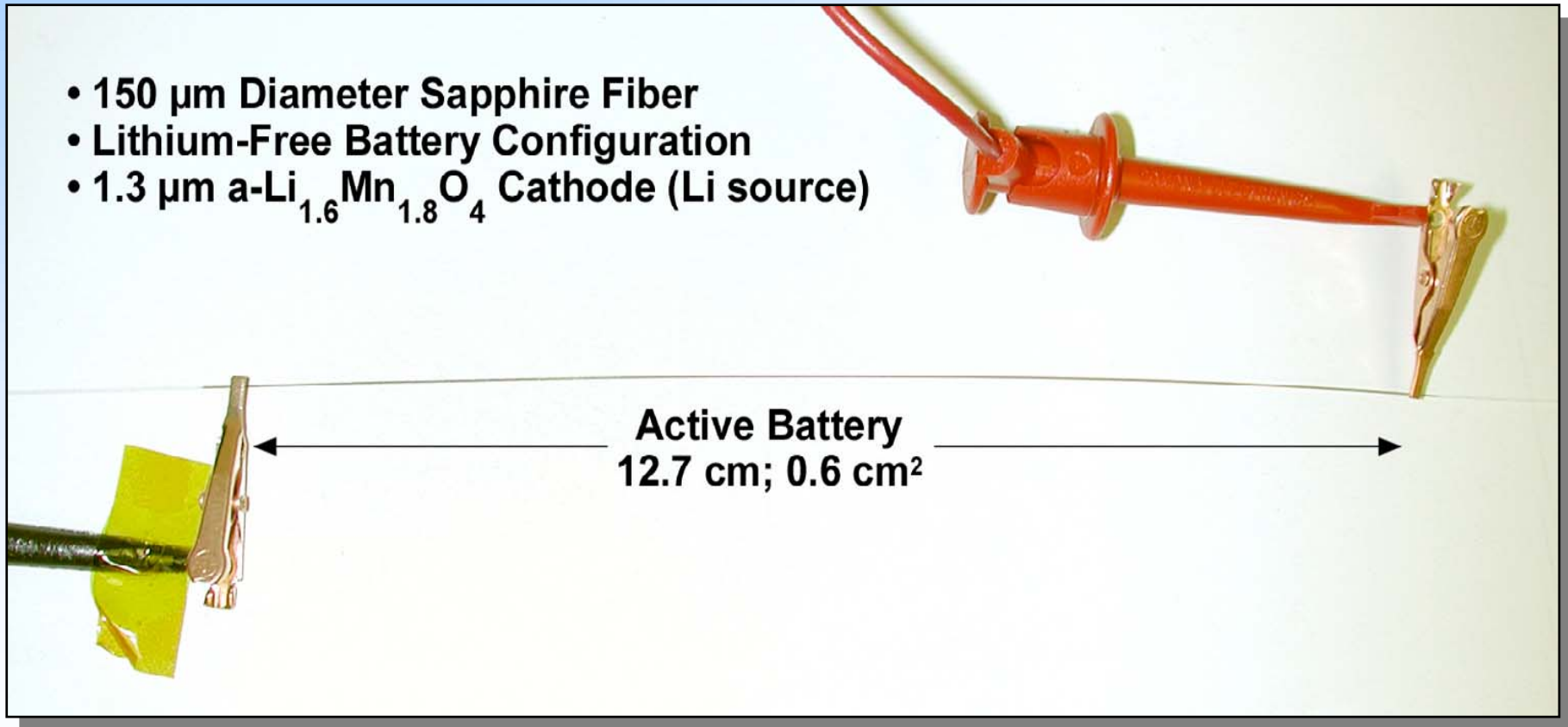


**"Buried  
Li-Free"**

# "Li-Free" PowerFiber on Sapphire - Electrochemical Testing -

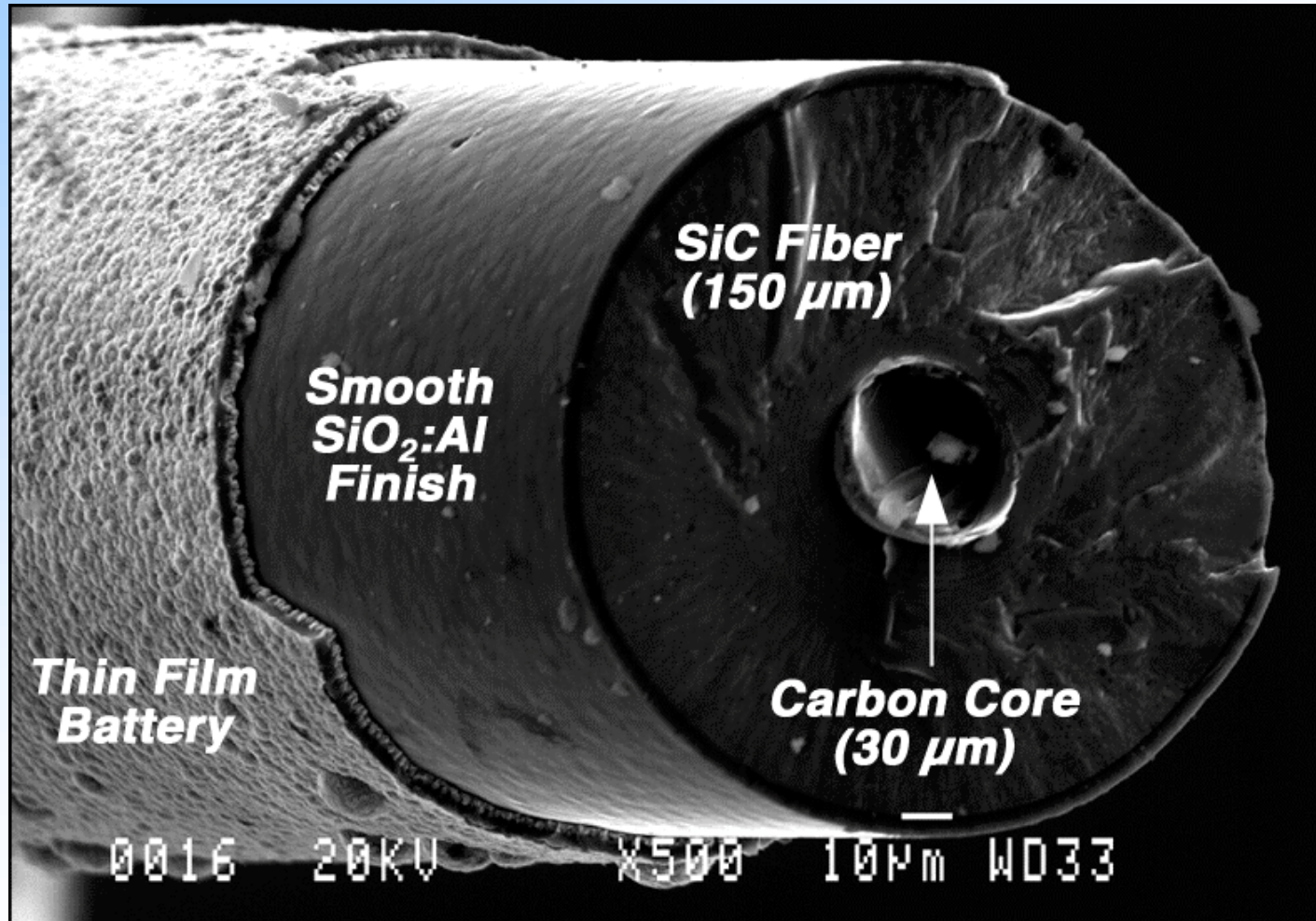
## ■ *First PowerFiber (February 2001)*

- 150  $\mu\text{m}$  Diameter Sapphire Fiber
- Lithium-Free Battery Configuration
- 1.3  $\mu\text{m}$  a-Li<sub>1.6</sub>Mn<sub>1.8</sub>O<sub>4</sub> Cathode (Li source)

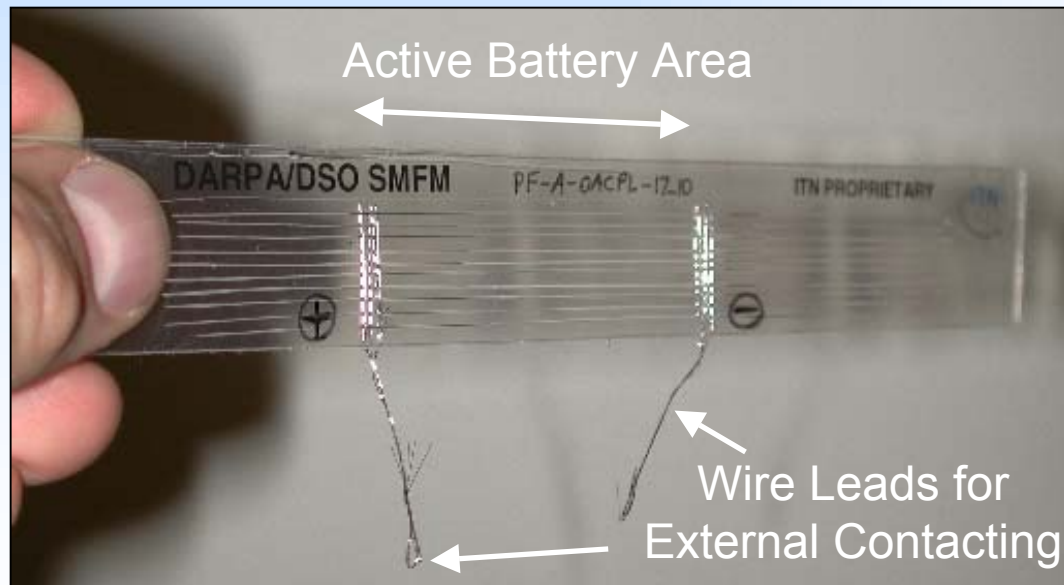
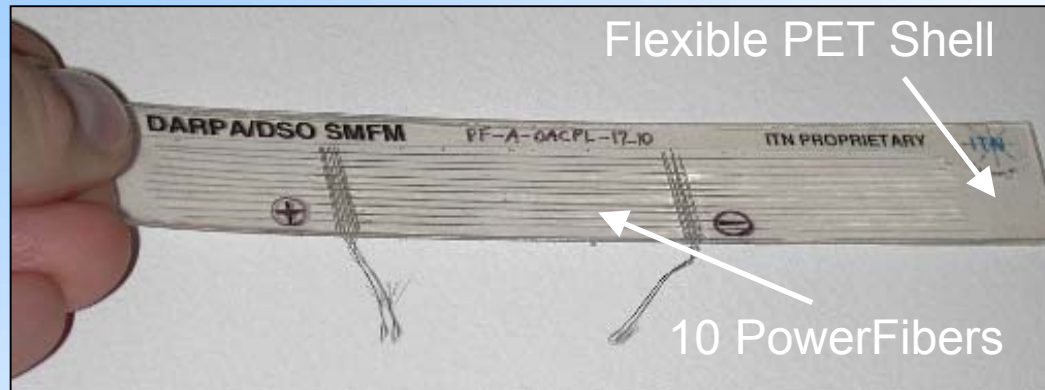




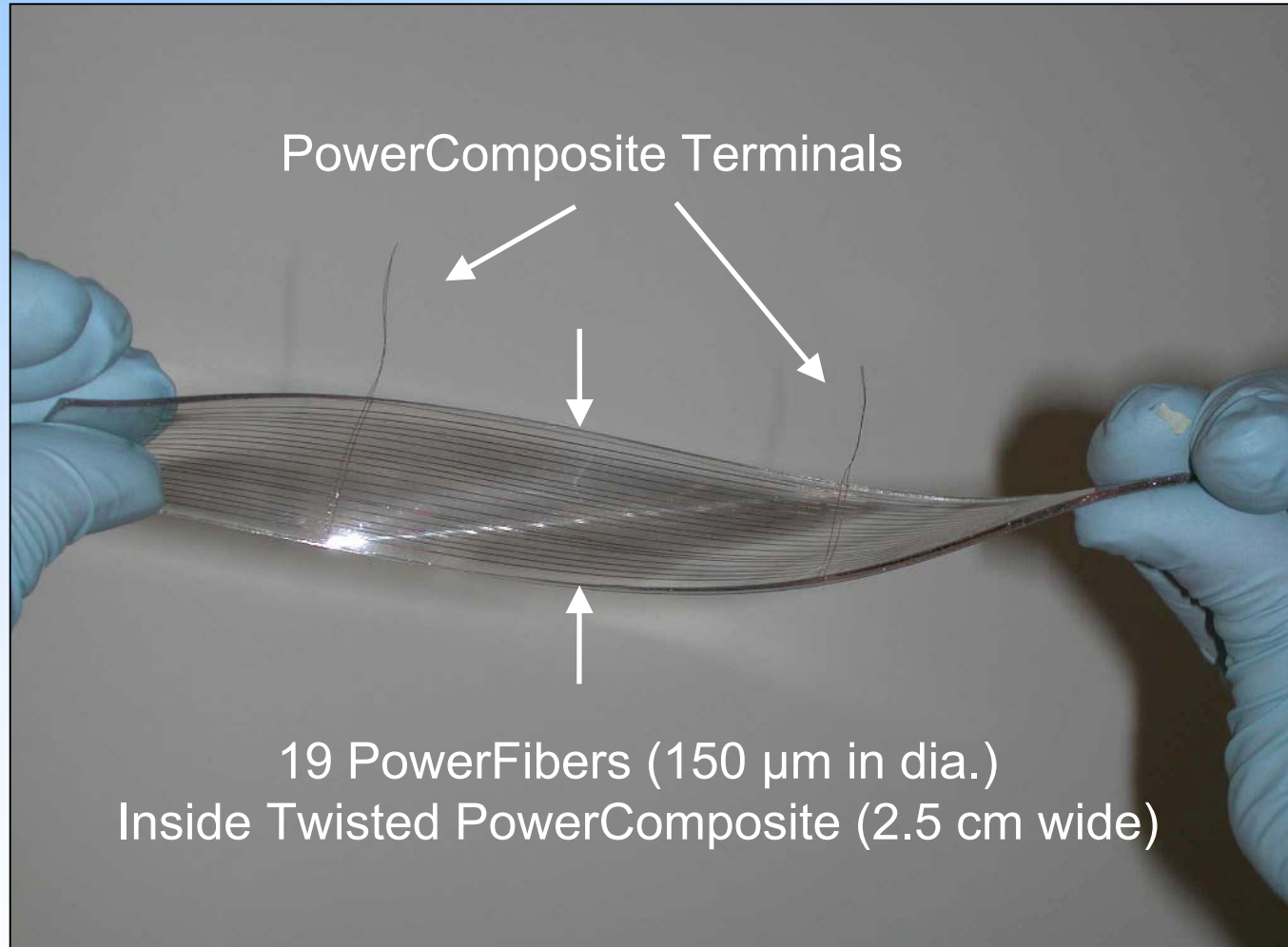
# SEM Micrograph of "Buried Li-Free" PowerFiber on SiC Fiber



# PowerComposite with 10 PowerFibers inside PET Matrix

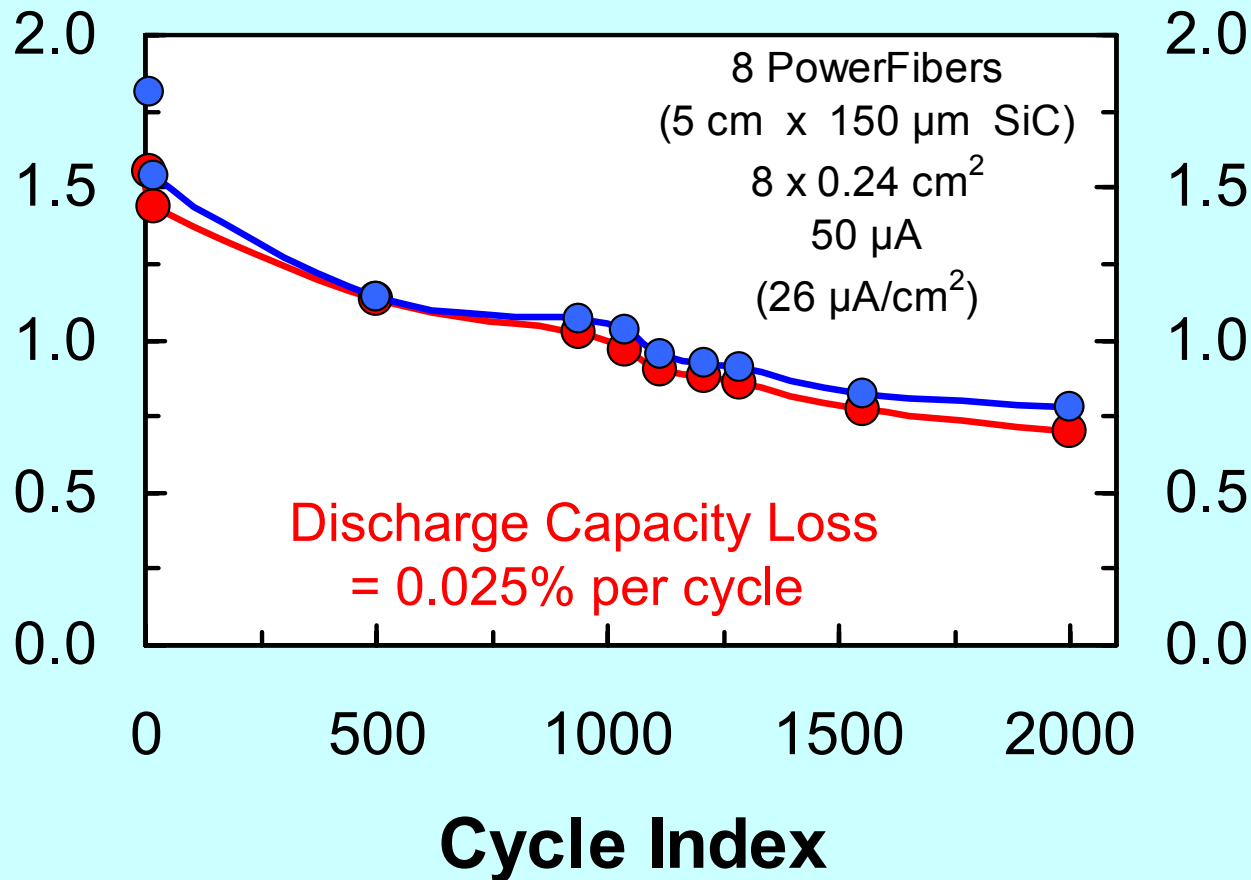


# PowerComposite: Electrochemical Testing under Deformation

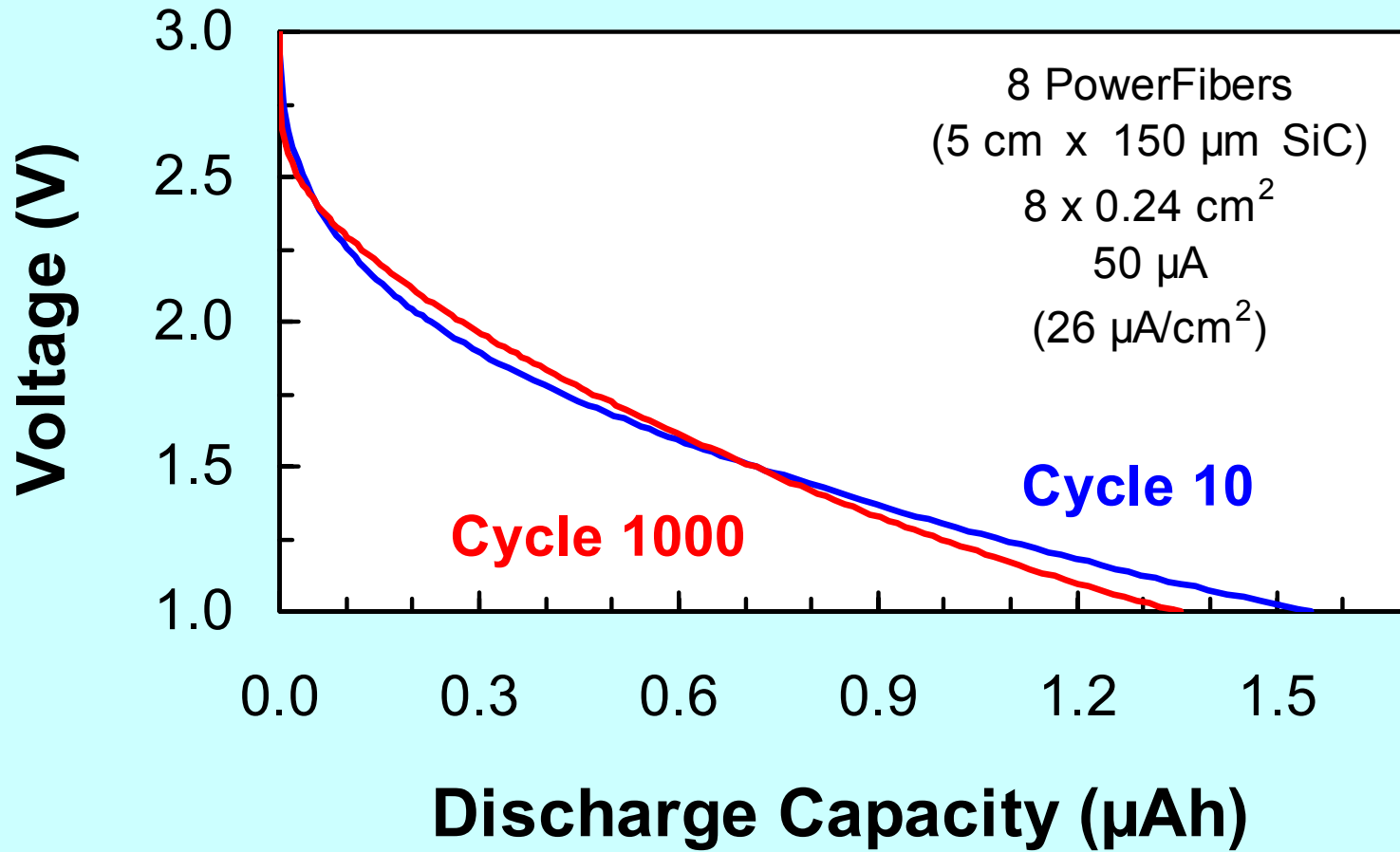


# PowerComposite ("Buried Li-Free" with $\text{Li}_2\text{V}_2\text{O}_5$ Cathodes)

Discharge Capacity ( $\mu\text{Ah}$ )



# PowerComposite ("Buried Li-Free" with $\text{Li}_2\text{V}_2\text{O}_5$ Cathodes)



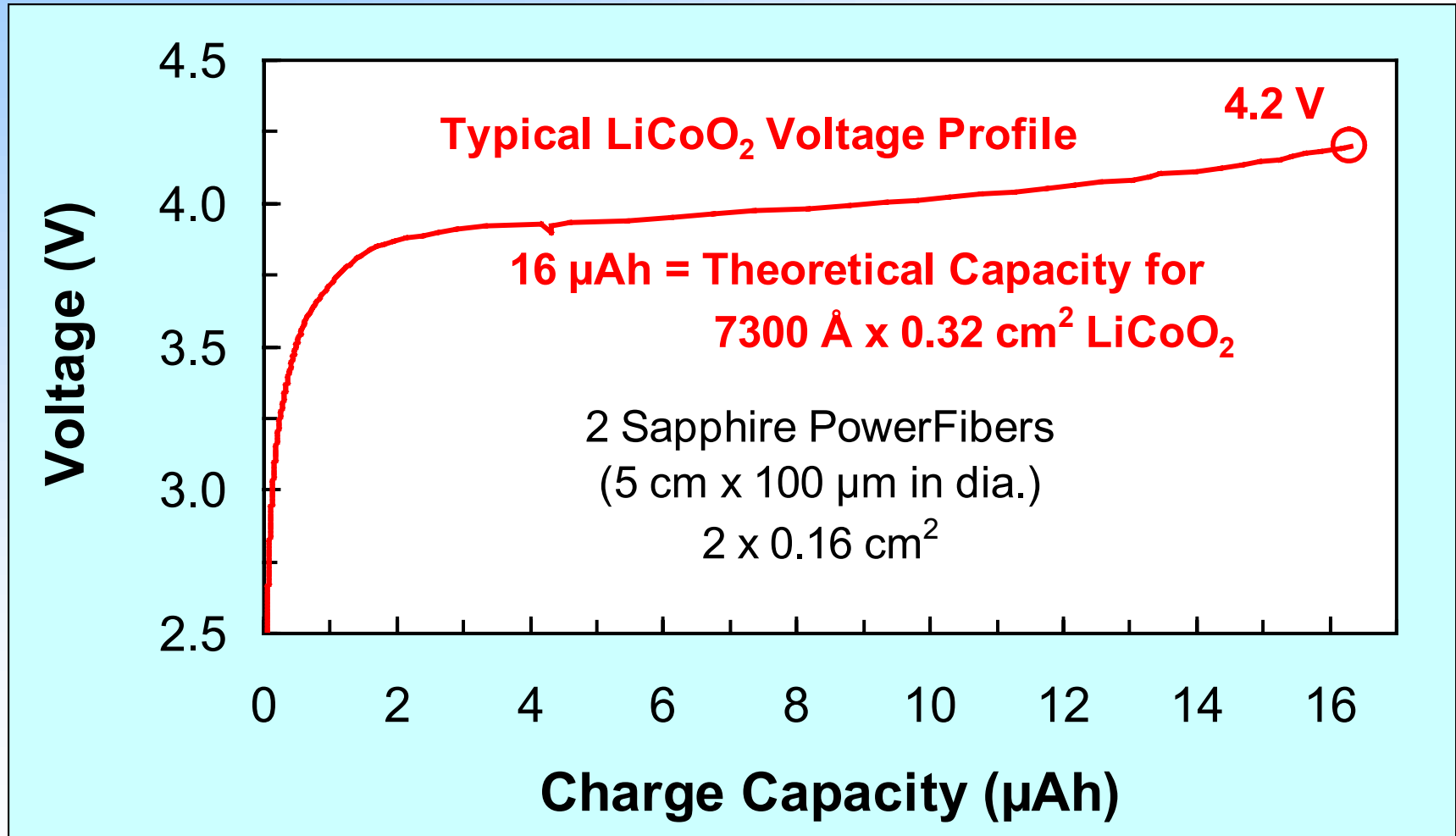


# PowerFiber Cathodes

- ***Cathodes (+) Determine Energy and Power !***  
Also: Voltage, Power, Weight, and Volume

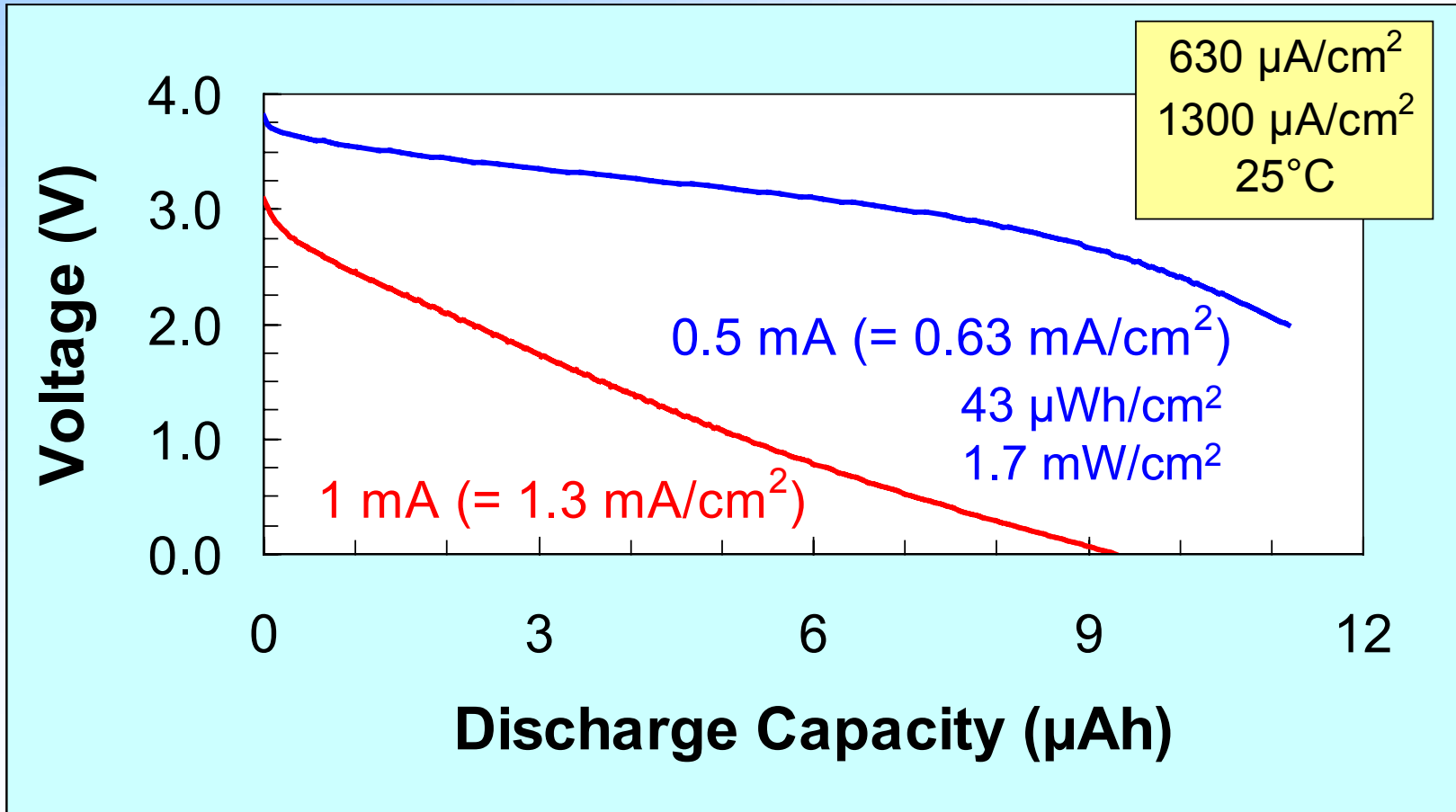
Year	Cathode Material	Relative Discharge Energy @ > 1 mA/cm <sup>2</sup>
2001	amorphous $\text{Li}_{1.6}\text{Mn}_{1.8}\text{O}_4$	1
2002	amorphous & crystalline $\text{Li}_x\text{V}_2\text{O}_5$	10
2002	<b>crystalline <math>\text{LiCoO}_2</math></b>	<b>&gt; 100</b>

# PowerComposite: "Li-Free" and $\text{LiCoO}_2$ Cathodes



# PowerFiber Rate Capability: “Li-Free” and $\text{LiCoO}_2$ Cathodes

- 1 mWh and 39 mW per 7m (23 feet) PowerFiber ( $\varnothing 100 \mu\text{m}$ )



# PowerFiber Technology Summary – Conclusions – Outlook



## ■ *ITN's Thin-Film Batteries @ 100% DOD*

- ❑ >2,000 demonstrated for PowerFibers (with challenging “Li-free” !)
- ❑ >90,000 demonstrated for flat configuration (38% overall capacity loss)
- ❑ Battery operation demonstrated between – 45°C to +120°C
- ❑ Battery life-time commensurate with device life-time

## ■ *Very Safe Inorganic Battery Technology*

- ❑ No fuming, no outgassing, no burning, no explosion, no thermal runaway
- ❑ Only limited local heat generation in case of accident
  - ] Small battery mass per unit length of fiber
- ❑ Controlled heat dissipation in PowerFiber network
  - ] Vastly spread-out heat sink

## ■ *Payoffs for Space and Aviation Applications*

- ❑ Spacecraft structure itself becomes a battery (increases payload)
- ❑ Distributed power storage (power structure is “everywhere” in space bus)



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**Paul DuPont (ITN)**

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